Calibrating the MicroBooNE Photomultiplier Tube (PMT) Array with Michel Electrons from Cosmic Ray Muons

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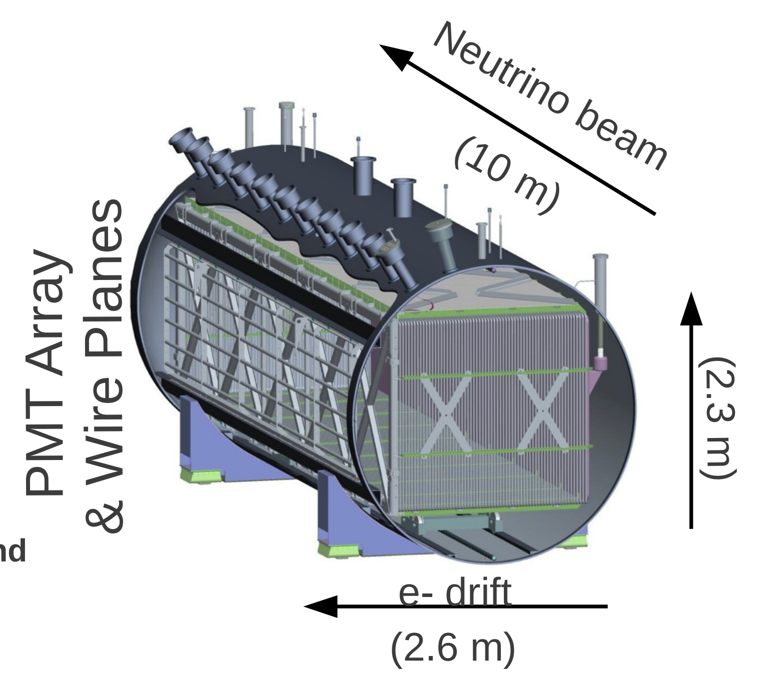
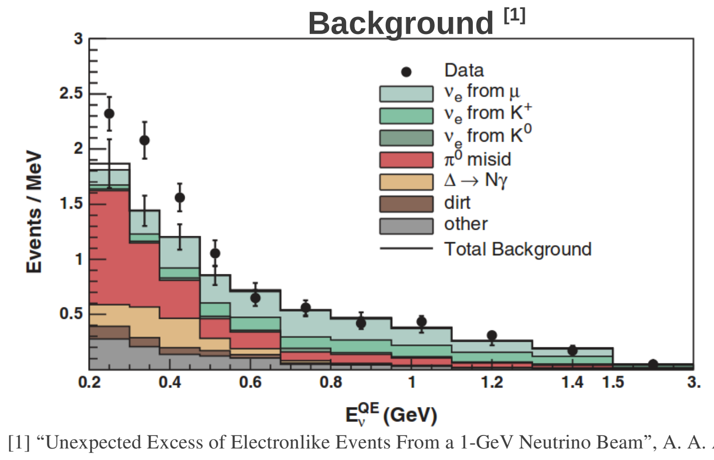
MicroBooNE

MicroBooNE is a 170-ton Liquid Argon Time-Projection Chamber (LarTPC) which is being constructed at Fermilab along the Booster neutrino beam line. MicroBooNE is expected to start collecting data in 2014, and will be used primarily to study neutrino oscillations and low-energy neutrino cross sections..

In particular, MicroBooNE is designed to investigate the 3-sigma low energy excess in electron-neutrino-like events seen by MiniBooNE. Unlike MiniBooNE, MicroBooNE will have the resolution necessary to distinguish electron events from photon events, which produce an electron-positron pair. If the excess comes from photon events, the excess likely comes from unanticipated background. However, if the excess instead comes from electron-events, the possibilities for new physics are much more exciting. MicroBooNE will also serve as an example for future larger LArTPCs.



MiniBooNE E_ν^{QE} Distribution for Data and Background [1]

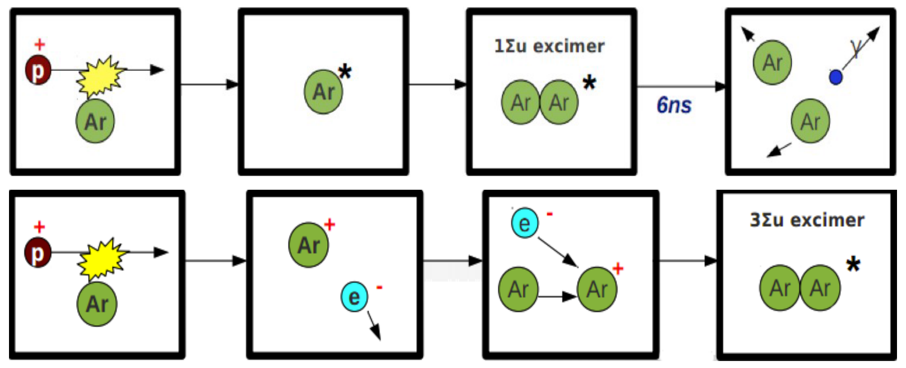


MicroBooNE will have two primary means of detecting passing neutrinos. An applied electric field will cause charged particles to drift towards MicroBooNE's three wire planes. Behind the wire planes, an array of PMTs will detect scintillation light produced by interactions within the TPC.

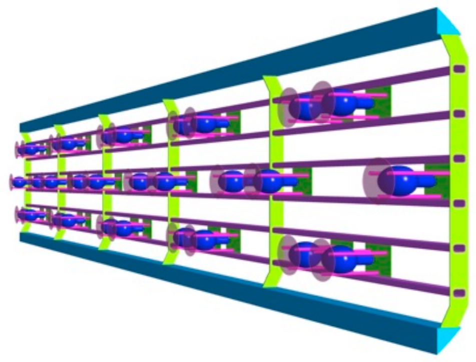
[1] "Unexpected Excess of Electronlike Events From a 1-GeV Neutrino Beam", A. A. Aguilar-Arevalo et al. MiniBooNE Collaboration. Phys. Rev. Lett. 102, 101802 (2009)

MicroBooNE's Light Collection System

When charged particles – such as electrons produced by neutrino interactions - pass through the liquid argon, they excite the argon atoms into higher energy excimers. When these excimers de-excite scintillation light is released.

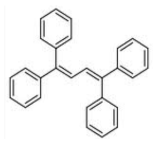


To detect this scintillation light, MicroBooNE will have an array of 30-32 cryogenic PMTs behind the wire collection plane.



The wavelength of light which is naturally emitted by liquid argon is around 128 nm. However, light at this wavelength cannot be directly detected by the PMTs, since it gets absorbed by the glass bulb and does not reach the PMT photocathode.

To compensate for this, each PMT will have in front of it an acrylic plate coated with the wavelength shifter tetraphenal butadiene (TPB), which will absorb the 128 nm light and re-emit it at 425-450 nm, which the PMTs can detect.



TPB – Tetraphenyl butadiene

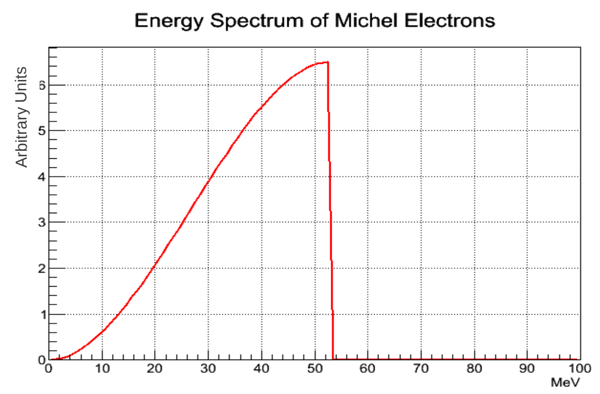
PMT with TPB-coated plate

Each TPB plate will have an associated quantum efficiency, which will determine how many photons reach the PMT. This quantum efficiency will vary from plate to plate.

Using Michel Electrons

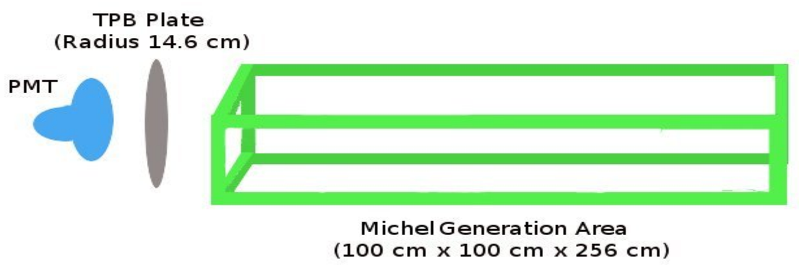
$$\mu^- \rightarrow e^- + \overline{\nu_e} + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu_\mu}$$

Cosmic ray muons are constantly passing through the MicroBooNE detector at a rate of 3-5 kHz. When cosmic rays muons stop, their decay produces an electron known as a Michel electron. Michel electrons have a very well-understood energy spectrum with a sharp cut-off at 53 MeV. This sharp cut-off and well-understood curve makes Michel electrons an excellent calibration source. By comparing the Michel electron energy spectrum as detected by each PMT, we can understand tube-to-tube variations in efficiency.



Toy MC Simulation

Within MicroBooNE itself, the observed energy spectrum of the Michel electrons will be smeared by effects from position, solid angle and quantum efficiency. I used a toy Monte Carlo simulation to study how these effects will appear within the detector.

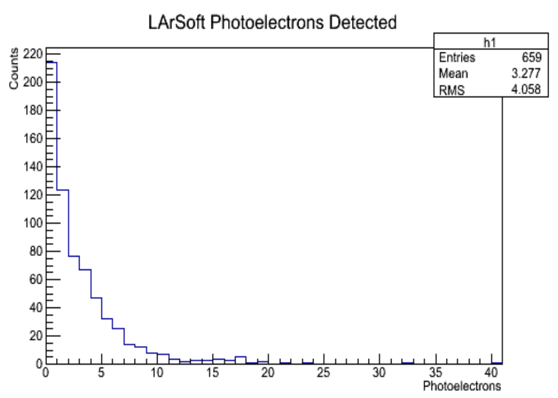


- Simulates light yield from Michel electrons from mu+ distributed uniformly over a box in front of each PMT, stretching the length of the detector
- Tube-to-tube variation in quantum efficiency distributed as Gaussian
- Scintillation Yield: 5490 γ/MeV
- Finding solid angle: Algorithm developed by Stanislaw Tryka[2]

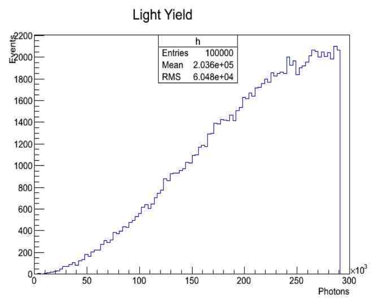
[2] Tryka, "A method for calculating the average solid angle subtended by a circular disk from uniformly distributed points within a coaxial circular plane". Rev. Sci. Instrum. 70, 3915 (1999)

Looking Ahead

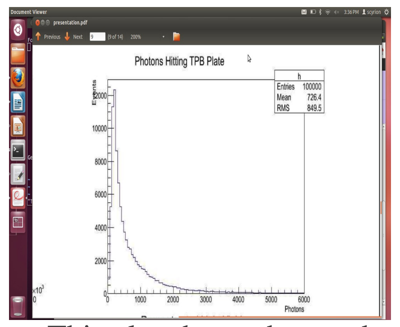
I plan on repeating this study on a full-scale MicroBooNE simulation through LArSoft, Ultimately, I hope to run my code on early PMT data to perform calibrations in tube-to-tube efficiency.



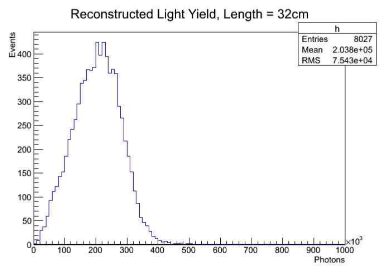
Results

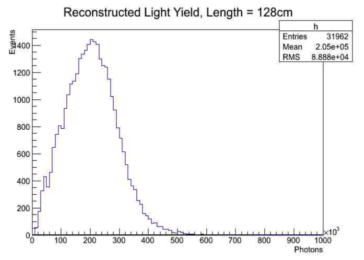


This plot depicts the light yield from the simulated muons. As expected, it is a Michel spectrum with an endpoint around 290000 photons, which corresponds to the Michel spectrum endpoint times the light yield: 53 MeV x 5490 photons/MeV.



This plot shows the number of photons hitting the TPB plate. This is what the distribution looks like after solid angle effects are included.





Using information from the TPC, the position of events can be reconstructed. Using this reconstructed position and the mean quantum efficiency, a reconstructed light yield can be found. These two plots examine reconstructed light yield for generation boxes of varying length. As the length of the box decreases, the reconstructed light yield curve approaches the convolution of Gaussian with the Michel spectrum.

A shorter box is desirable because it results in a reconstructed muon distribution that is easier to fit. From such a fit, the quantum efficiency can be extracted. However, using a smaller box means that it will take more time to gather sufficient statistics for calibration.

There are other metrics for tracking quantum efficiency. After studying how the maximum and endpoint and mean of the distribution change with quantum efficiency, I concluded that the mean is the most linear.

From this plot it is clear that the mean of the reconstructed photon distribution is a good heuristic for quantum efficiency.